Photosynthesis as a Possible Source of Gas Bubbles in Shallow Sandy Coastal Sediments

D.V. Holliday
Graduate School of Oceanography
University of Rhode Island
(deceased)

C.F. Greenlaw
302 Tailwind Drive
Seguin, TX 78155
phone: (830) 372-3239 fax: (401) 874-6240 e-mail: cgreenlaw@xetexracing.com

David Thistle
Department of Oceanography
Florida State University
Tallahassee, FL 32306-4320
phone: (850) 644-4089 fax: (850) 644-2581 e-mail: dthistle@fsu.edu

Jan E.B. Rines
University of Rhode Island
Graduate School of Oceanography
South Ferry Road
Narragansett, RI 02882-1197
phone: (401) 874-6691 fax: (401) 874-6240 e-mail: jrines@gso.uri.edu

Award Number N00014-09-10491

LONG-TERM GOALS

Our long-term interests involve the possibility that biogenic activity can influence acoustic scattering at the water column-seabed interface and the propagation of sound in and over a sandy substrate in a shallow-water coastal marine environment. Evidence from laboratory studies on sand collected from the surf zone clearly demonstrates that gas bubbles can be formed when photosynthesis by benthic microalgae causes pore water to become supersaturated with oxygen.

OBJECTIVES

The next logical step is to determine whether this phenomenon occurs in the coastal ocean. The near-term objective of the work is to determine whether photosynthesis produces conditions that lead to the formation of oxygen bubbles in the top few millimeters of shallow sandy coastal sediments and, if it does, how such bubbles change the acoustic reflectivity of the seabed.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Photosynthesis as a Possible Source of Gas Bubbles in Shallow Sandy Coastal Sediments**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Rhode Island,Graduate School of Oceanography,Narragansett,RI,02882**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**11**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

APPROACH

In the laboratory, exposure of natural sand from a beach in Panama City, FL, was observed to scatter broadband sound in different amounts throughout a diel cycle (Figure 1).

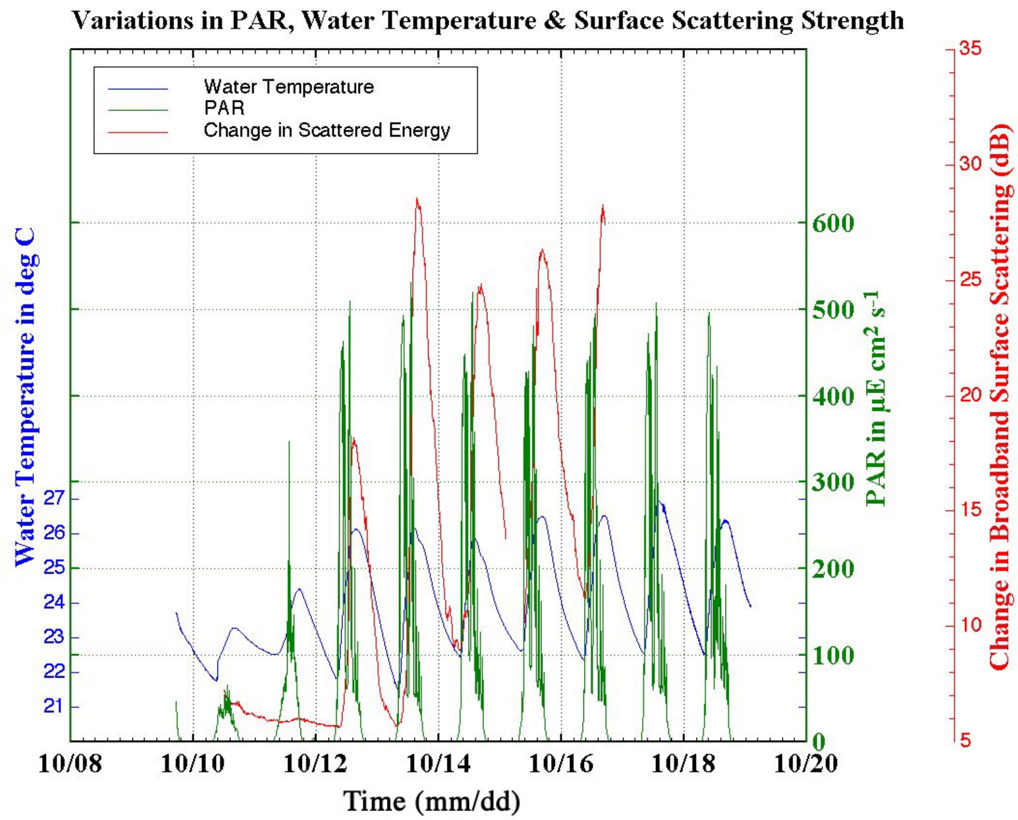

Figure 1: Diel variations in the broadband (100 kHz to 900 kHz) acoustical scattering from a bed of sand (red), the water temperature (blue), and photosynthetically active radiation (green) as measured in a laboratory aquarium exposed to natural sunlight via a neutral density film over a glass window. The resulting light levels simulated a depth of ca. 20 m. Water temperature (blue) was also measured, and the changes were determined to be too small to have caused the increases in scattering. The sand was from a beach in Panama City, FL. A 30 dB change in scattering is equivalent to an increase of 1000 times.

The variations in scattered sound were synchronized with, but lagged, diel changes in light levels incident on the bed of sand. Bubbles were seen on the surface of the sand during periods of high scattering. This observation strongly suggests that photosynthesis created sufficient oxygen to cause supersaturation in the pores between the sand grains. This eventually led to the formation of small bubbles that then migrated to the sediment-water interface, coalescing during and after the migration to form larger bubbles that were visible to the naked eye. The acoustic scattering from the bubbles then caused increases in the broadband scattering from the bed of sand, as more bubbles were formed and those present grew in size during the day. In the absence of sunlight, the bubble numbers and sizes were reduced, either by release of the bubbles when their growth or buoyancy exceeded the forces keeping them in place on the sand surface or by reabsorption of the gas into the water after oxygen production slowed and finally ceased during the dark hours. Additional details regarding the laboratory experiment can be found in Holliday *et al.* (2004) and Holliday (2009).

Our objective is to determine whether the phenomenon observed in the laboratory also occurs in the sea. We have developed equipment that will allow us to obtain backscattering data from the seabed and to examine it for the temporal changes that would be expected should the production of oxygen be sufficient to produce bubbles. We have also developed equipment (i.e., a time-lapse underwater camera) to investigate other possibilities (e.g., biological roughening).

We initially tested our equipment at a 5-m deep site on the north Florida shelf in the Gulf of Mexico (29° 52.169' N, 84° 26.428' W). This site is well documented (Teasdale, Vopel, and Thistle, 2004). The seabed is well-sorted, unconsolidated medium sand. Storms occasionally cause sediment resuspension and ripple fields can be created. In order to get unambiguous answers regarding the source of any observed change in scattering, we also deployed a time-lapse camera to record conditions in the field of view of the acoustic sensor to allow us to separate macroscale physical changes in the bottom topography from biological processes other than bubble production that lead to changes in the acoustic reflectivity. We also collected sediment samples from the upper few mm of sand to identify the dominant taxa of benthic microalgae present.

After review of the several deployments in this test site, with mixed results, we elected to attempt a deployment in a region of clearer water in St. Joe Bay, FL. The advantage of the original site was the ability to recover gear from the bottom without the use of surface buoys. Theft is a serious problem in the coastal waters in this area. We elected to risk the equipment for this (potentially final) deployment, however. In light of the risks, we did not deploy any more expensive gear than was absolutely necessary for the experiment.

Charles Greenlaw prepared and bench tested the acoustic (Figure 2) instrumentation for this research project. David Thistle from Florida State University (FSU) provided ancilliary sensors, tested the equipment in the field, prepared the benthic lander (Figure 3) for making oxygen profiles in the sediment, and has collected samples for Jan Rines (Graduate School of Oceanography / University of Rhode Island (GSO/URI) to identify the benthic microalgae in the samples. Following the untimely death of Dr. D.V. Holliday, the remaining team members are sharing the responsibility of analyzing data and preparing such presentations and publications as may be merited based on our results.

Figure 2: The Sand Scan acoustic sensor consists of a broadband acoustic transducer, a small green cylinder shown here on a movable arm at the upper left of the instrument. The white pressure case contains the electronics necessary to transmit a sequence of 200-microsecond pulses at several discrete frequencies between ca 0.22 and 0.335 MHz, receive the echoes from a small area on the seabed, and store digital representations of the received bottom reverberation waveforms. The black cylinder contains batteries. For scale, the tiles on the lab floor were 1 foot on each side. A later version of this instrument added another case containing a datalogger to extend the deployment duration to up to two weeks.

Figure 3: Shown here on shipboard, FSU's battery powered, autonomous, benthic lander measures oxygen-concentration profiles in unconsolidated sandy sediments. Up to four oxygen probes mounted at the bottom of the black cylinder are mechanically driven into the sediment and measurements are made at sub-millimeter intervals. An internal computer controls a motor via software that is programmed to collect a profile at time and depth intervals specified before the lander is deployed on the sea floor. Data are recorded internally and retrieved when the lander is recovered. The ring on top of the lander is used for attaching a hook or line during deployment and recovery operations. For scale, the black electronics cylinder is ~ 6 inches in diameter.

WORK COMPLETED

We modified the SandScan acoustic sensor to provide the capability of echo ranging over a slant range of 1.7 m. The range resolution is now *ca*. 15 cm, depending on the speed of sound near the seabed. The sensor sequentially transmits 200-microsecond pulses at seven discrete frequencies between 0.220 and 0.335 MHz, which spans much of the range of frequencies that produced large scattering strength changes in the laboratory experiment. Sufficient battery power and memory was installed to allow recording of a complete data set of 24 pings per frequency every 20 minutes for about a week. The benthic lander has also been refurbished and configured for use in this project.

SandScan outputs raw echo amplitude samples in digital format to the associated acoustic datalogger. These amplitudes are downloaded and processed post-deployment. Normal processing includes estimating the mean bottom backscattering echo in each range bin and correcting each channel for system response. The expectation was that the bottom backscattering echoes would show some temporal correlation with incident light as measured by a light sensor near the SandScan.

SandScan was deployed on five occasions in 2010. Two deployments (March and August) resulted in no data due to equipment failures. Two deployments (April and June) netted ten days of bottom scattering data. On the August deployment, the light meter's data logger failed, and no PAR data were recorded but acoustic data were obtained. The system had been deployed with a replacement data logger for PAR. Our time-lapse camera was also deployed this time but the pictures were too murky to be of much help.

The last deployment was in July of this year. We decided to move the test area to a region of clear water and sandy sediments in St. Joe Bay, FL. The risk of loss due to theft was weighed against the potential benefits of the clear water and, since the grant was coming to an end, we elected to risk the equipment. SandScan was deployed this time with only logging irradiance meters to minimize the loss of gear in case of an incident. The equipment was deployed in approximately 1 m of water, too shallow to permit deploying the benthic lander.

The results of the 2010 deployments have been reported previously. Although these data showed variability over time -- sometimes fairly dramatic variability -- there was no clear diel signal at all. Our conclusion is that the probable cause of variation in the backscattering strength at this site was migration of sand dollars through the area.

The data from this deployment revealed a very clear diel change in the acoustic backscattering from the bottom, in synchrony with the incident irradiance. Figure 4 displays the mean backscattered bottom echoes, corrected for system gains, at the seven frequencies of the SandScan compared with the logged incident irradiance. It is evident from this data that there is a marked change in bottom backscattering strength over a diel cycle of as much as 20 dB (a change in backscattered intensity of 100 X) or more and, over several days, of as much as 30 dB (a change in backscattered intensity of 1000X). These results are, if anything, even stronger than the results obtained in the laboratory -- a remarkable result.

The same data can be plotted as backscattering spectra versus time (Fig. 5). This view emphasizes the relatively flat spectrum of the backscattering which is characteristic of backscattering from bubbles.

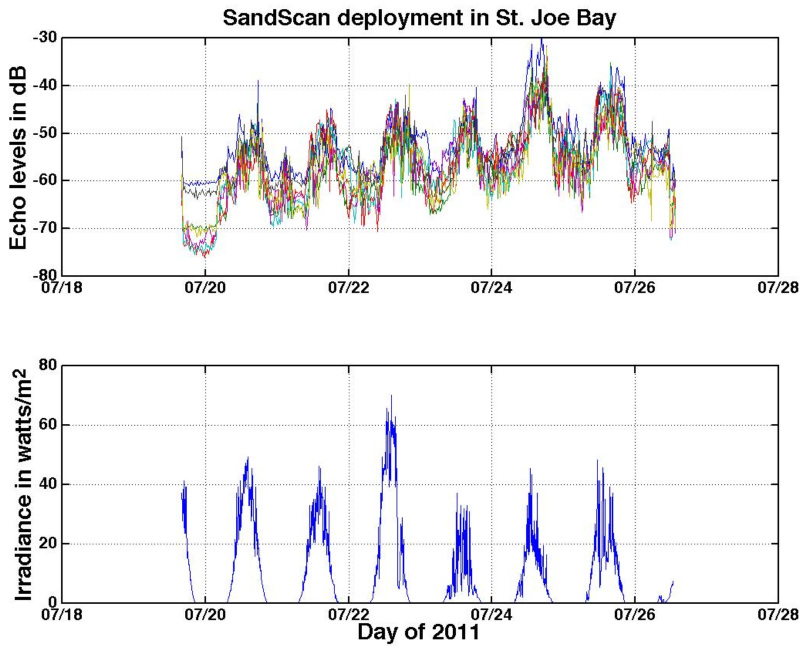

Figure 4. Plot of averaged bottom echo intensity (upper) at seven frequencies from 220 - 335 kHz versus time. Irradiance data recorded at the same site are shown in the bottom plot. The acoustic data shows strong diel variations that are clearly associated with the irradiance at the bottom sands.

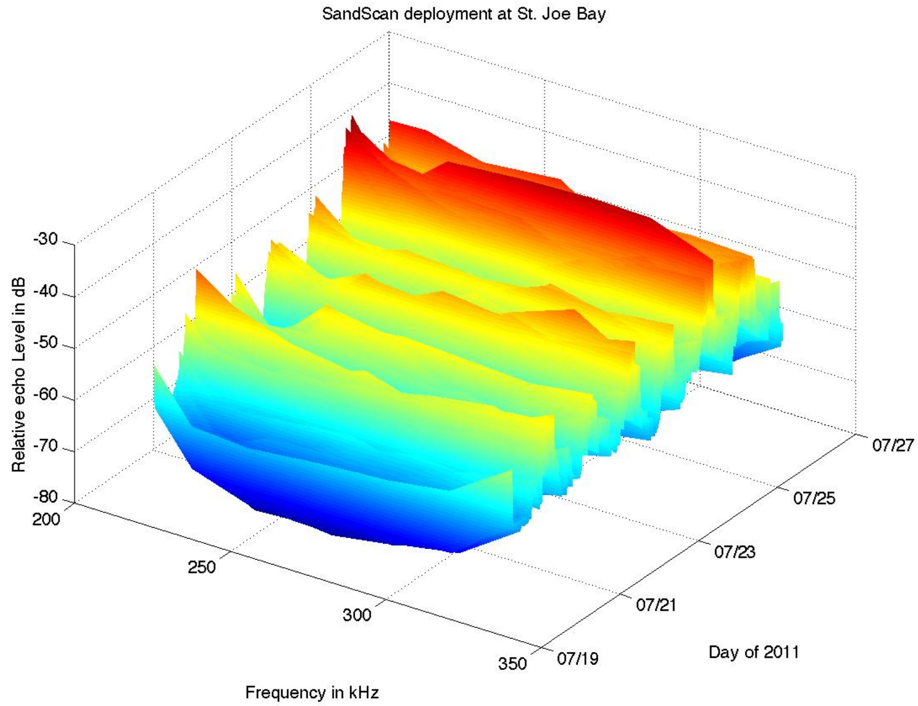

Figure 5. Bottom backscattering echo intensity versus frequency and time. Higher backscattering is shown in warm colors (reds) and lower backscattering shown in cool colors (blue). Echo data have been corrected for system gains. The color bar is scaled in dB.

Sand samples were collected at the deployment site on 27 July and sent on dry ice to Rhode Island, where they were thawed and qualitatively examined. Some sand samples were noticeably pink. When examined on the microscope, a variety of pennate diatoms and both blue-green and red cyanobacteria were observed (Figure 6). Some cells were loose, indicating that they had been living interstitially, whereas others were attached to the surface of sand grains. In spite of having been frozen and thawed, cells appeared highly pigmented, thus should have been capable of very active photosynthesis.

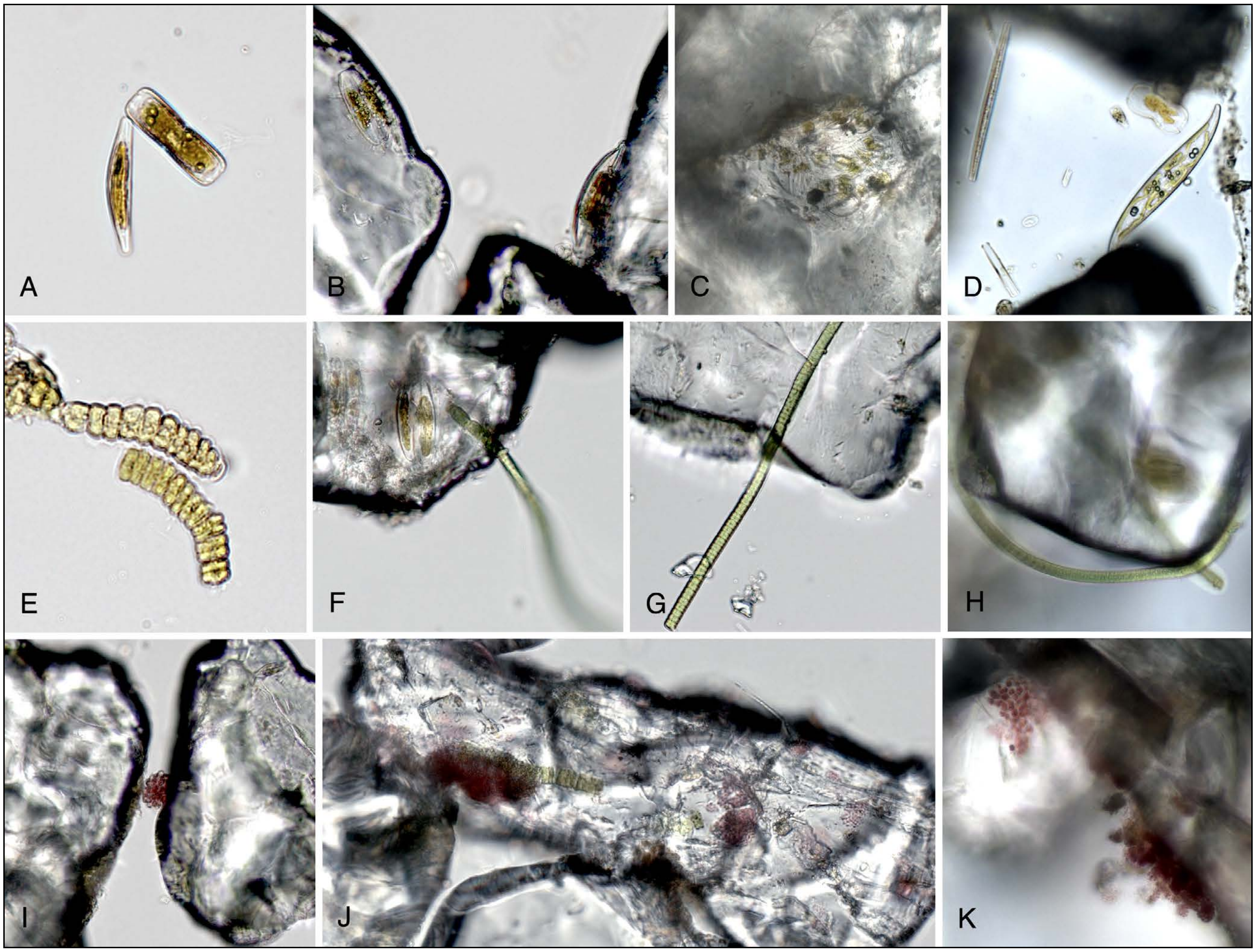

Figure 6. Photomicrographs of sand samples and benthic microalgae collected from the deployment site in St. Joe Bay on 27 July 2011. These brightfield images depict a variety of pennate diatoms and cyanobacteria. A, D, free living, interstitial pennate diatoms. B, C, diatoms attached to the surface of sand grains. E, interstitial cyanobacterial colony. F-H, filamentous cyanobacteria. I-K, clusters of red, coccoid cells, which we believe to be cyanobacteria, attached to sand grains.

The SandScan is to be deployed again in October at St. Joe Bay, to see if the July result is non-unique.

CONCLUSIONS

The observations in the laboratory that led to this field work have been confirmed at one site. The expectation that benthic algae can cause super-saturation of oxygen and that this gas can come out of solution in the sand sediments appears to be justified. It remains to be seen whether or not this is a ubiquitous phenomena. The results of the October deployment should be useful in this regard.

IMPACT/APPLICATIONS

The answers to the questions we are addressing have implications for understanding:

1) the stimuli cuing emergence,
2) the role of bubbles in scouring surficial sediments,
3) the performance of naval sensors used to detect objects on, in, or near the seabed,
4) the characteristics of acoustic communications channels in shallow water,
5) the development of mathematical models for seafloor sound scattering,
6) and, the limitations and benefits of acoustic methods now being proposed and used for classifying, describing, and mapping benthic habitats in the littoral zones of many coastal nations.

RELATED PROJECTS

Markus Huettel, one of David Thistle's colleagues at Florida State University, has been funded by ONR to study bubbles in near-shore, sandy sediments. In one subproject, he will investigate their distribution along transects in the sub-littoral. We had originally planned to deploy our gear near one of Dr. Huettel's sites in order to independently test the relationship between the acoustic properties of the sediment and the variables he is measuring. The presence of significant amounts of shell hash at those study sites has caused us to change our approach. Should one of the oxygen probes, made of glass, encounter a shell as it is forced into the bottom, it would be broken. Our revised plan was to work at a 5-m site where David Thistle has done oxygen sensor work previously. That site is relatively free of shell fragments. We provided Dr Huettel with cores from the Thistle site. They will become part of his project, broadening his work in time and space and providing us with additional information about our study site.

REFERENCES

Holliday, D.V., C.F. Greenlaw, J. E. B. Rines, and D. Thistle. 2004. Diel variations in acoustical scattering from a sandy seabed. Proceedings of the 2004 ICES Annual Science Conference, Vigo, Spain. ICES CM 2004/T:01, p. 23 (A). (Full paper on the Conference CD ROM; available on request).

Holliday, D.V. Technology for Evaluating Marine Ecosystems in the Early 21st Century. 2009. Chapter 17 in *The Future of Fisheries Science in North America*, Beamish, Richard J. and Rothschild, Brian J. (Eds.), Springer-Verlag Fish & Fisheries Series, Vol. 31: 293-311, doi:10.1093/icesjms/fsp127.

Teasdale, M., K. Vopel, and D. Thistle. 2004. The timing of benthic copepod emergence. Limnology and Oceanography 49: 884-889.

PUBLICATIONS

Holliday, D.V. Technology for Evaluating Marine Ecosystems in the Early 21st Century. Chapter 17 in *The Future of Fisheries Science in North America*, Beamish, Richard J. and Rothschild, Brian J., Eds.

Springer-Verlag Fish & Fisheries Series, Vol. 31: 293-311, doi:10.1093/icesjms/fsp127. [published, refereed.]

Holliday, D.V., P.L. Donaghay, C.F. Greenlaw, J.M. Napp, and J.M. Sullivan. 2009. High-frequency acoustics and bio-optics in ecosystems research. ICES Journal of Marine Science 66: 974-980, doi:10.1093/icesjms/fsp127. [published, refereed.]

Holliday, D.V., C.F Greenlaw and P.L. Donaghay. 2010. Acoustic scattering in the coastal ocean at Monterey Bay, CA USA: Fine-scale vertical structures, Continental Shelf Research 30: 81-103. [published, refereed.]